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# **TPS Enhancement Options**

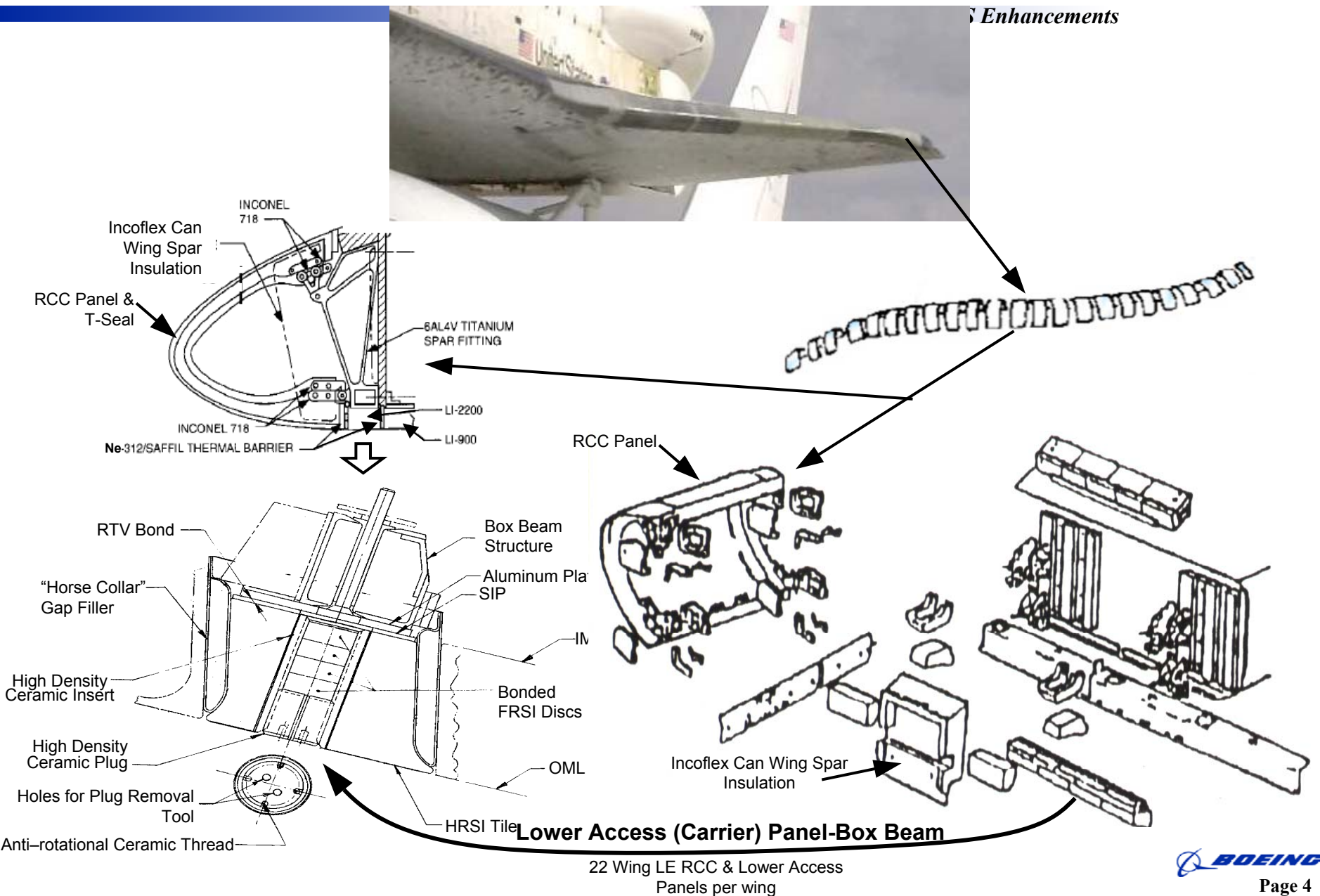
**September 16, 2003**

- ♦ **STS-107 accident has shown that Thermal Protection System (TPS) design is vulnerable to impact damage for conditions outside of current design criteria**
  - ♦ Decreasing that risk for damage (Orbiter Hardening) is can be addressed by making the structure less vulnerable to impact damage
  - ♦ Design modification options can address changes which are expected to make the Orbiter less vulnerable to the risk, not abate the overall external risk

## **Six Critical TPS Areas Targeted For TPS Enhancements**

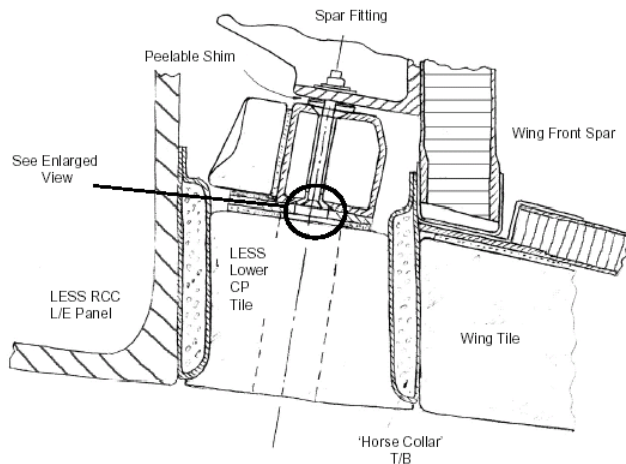
1. WLESS Redesign
2. Gear and ET Door Redesign
3. Carrier Panel Upgrades To Eliminate Bonded Studs
4. Durable Tile (BRI 8, BRI 20)
5. Elevon Leading Edge Carrier Panel Redesign
6. White TUFI and Vertical Tail AFRSI High Emittance Coating

# 1. Wing Leading Edge Subsystem— Areas of Concern



# 1. WLESS Redesign TIM Actions

*TPS Enhancements*



## ♦ Integrated solution can provide additional protection against impact & plasma flow vulnerability:

### ♦ Lower Access Carrier Panel Redesign

- ♦ Four options require trade study
  - Option 1 Stronger Access Panel Fasteners
  - Option 2 WLESS Extended Carrier Panel
  - Option 3 Box Beam Removal
  - Option 4 Simplified Leading Edge Access Panel Installation

- ♦ Redesign Insulators to Add High Temperature Insulation
- ♦ Add Front Spar Protection
- ♦ Incoflex Insulator Redesign
- ♦ Evaluate use of Yttria Zirconia Coating on Surfaces of Insulation Panels

# 1. WLESS Redesign Forward Plan

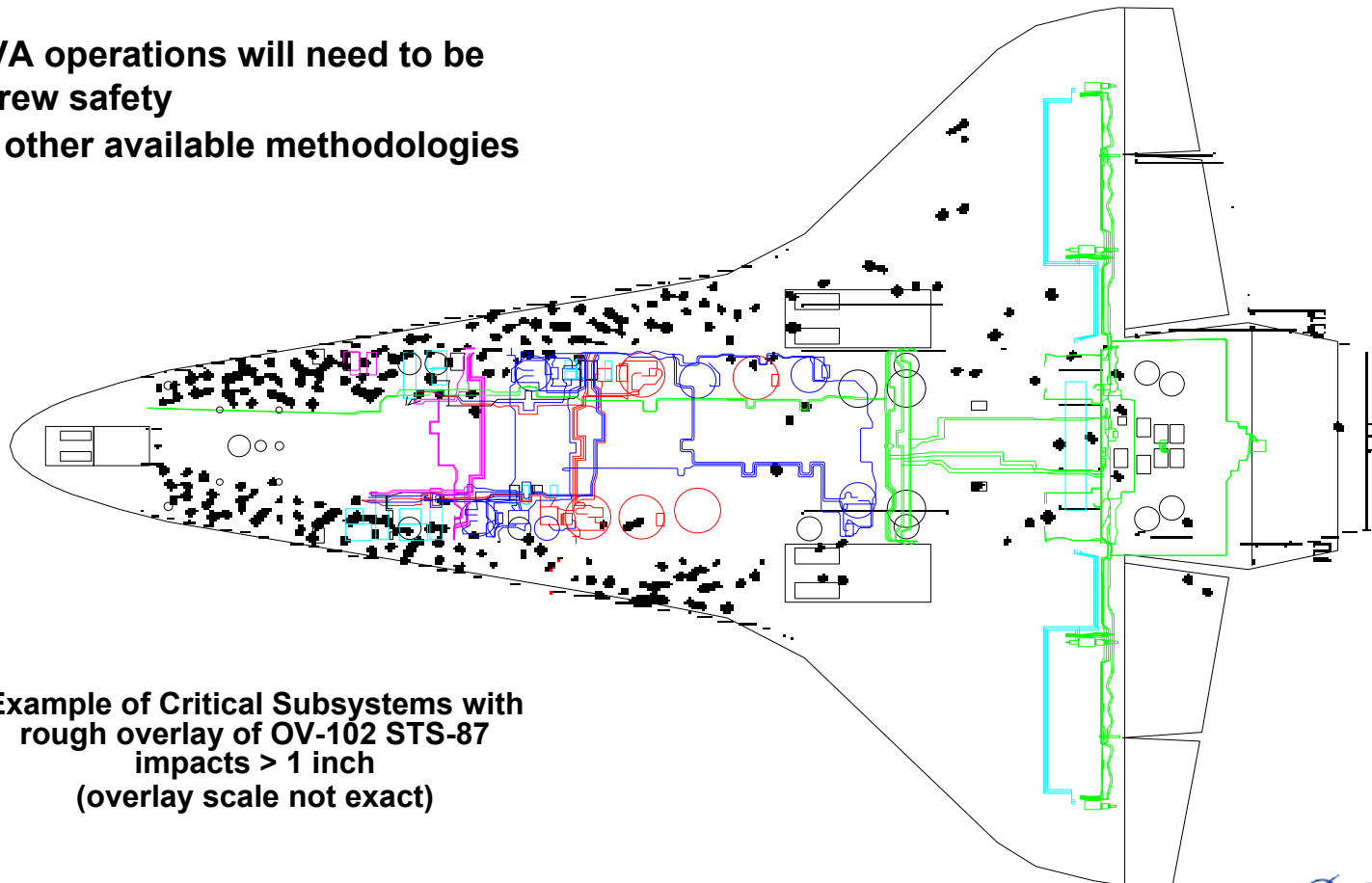
*TPS Enhancements*

Change Item	Rationale for Change
<b>1. WLESS</b>	
Lower Leading Edge Access Panel <b>Impact and Temperature Resistance</b> Redesign	<b>1.</b> Redesign access panels to make them more robust against impacts and more temperature resistant <b>2.</b> Redesign goal: Provide fail safe design, redundancy, impact tolerance, eliminate flow paths with addition of thermal barrier, use higher temperature resistant materials
Front Spar Protection	<b>1.</b> Redesign to add temperature resistant materials on exposed areas of the front spar <b>2.</b> Redesign goal : Provide redundancy and allow additional time for Orbiter to survive reentry conditions in the event of a breach in the WLESS
Incoflex Insulator Redesign	<b>1.</b> Redesign to add more layers temperature resistant materials inside all off the Incoflex insulators and/or add temperature resistant materials to the insulator exterior <b>2.</b> Redesign goal : Provide redundancy and allow additional time for Orbiter to survive reentry conditions in the event of a breach in the WLESS
Evaluation of Yttria Zirconia Coating	<b>1.</b> Higher temperature capability material used on other program applications may have beneficial use on WLE surfaces since the melting point of Yttria Zirconia coating is 5000 degree F. <b>2.</b> Use of temperature resistant material Yttria Zirconia coating on exposed areas of the inside of the WLESS may allow for more time for Orbiter to survive reentry conditions in the event of a breach in the WLESS.
Robust RCC	Redesign RCC panels to make them more robust against debris impacts while maintaining intended performance requirements of wing leading edge subsystem.

## 4. Lower Surface Acreage Tile - Issues

*TPS Enhancements*

- Impact damage at adjacent tiles beyond 1 tile and/or at a critical location can result in LOV
- Post-flight TPS repair is the second longest flow task
  - Lower surface tile average ~ 100 impacts/flight
- Contingency EVA inspection & repair will be difficult & complex
- Contingency EVA operations will need to be minimized for crew safety
- Need to assess other available methodologies



Example of Critical Subsystems with  
rough overlay of OV-102 STS-87  
impacts > 1 inch  
(overlay scale not exact)

## 4. Tougher Lower Surface Tile (BRI 8/12/20)

*TPS Enhancements*

- ◆ **Complete tougher tile (BRI-8 and BRI-20) development**
  - ◆ BRI-8 development funded by Upgrades + X-37 (complete December 2003)
  - ◆ BRI-20 development fully funded by X-37 (complete August 2003)
  - ◆ Delta Orbiter certification required
  - ◆ BRI-8 replaces HRSI LI-900
  - ◆ BRI-20 intended to replace HRSI LI-2200 and HRSI FRCI-12 type tiles
- ◆ **Complete Ballistic SIP development (partially funded by Shuttle IRAD)**
  - ◆ Requires additional development funding
  - ◆ Requires full Orbiter certification
  - ◆ Goal to keep BRI-8 and Ballistic SIP schedules in parallel
- ◆ **Define lower acreage tile implementation plan**
  - ◆ Define methodology to prioritize implementation
  - ◆ Address low velocity (ascent) impact risk areas
  - ◆ Address high velocity (MMOD) impact risk areas
- ◆ **Implement tougher tiles (BRI-20)**
  - ◆ ET Door periphery, MLGD periphery, NLGD periphery, Elevon Leading Edge and Wing Trailing Edge carrier panel tiles and Window Frames
- ◆ **Complete BRI-12 development (current minimal dev funding from Orbiter)**
  - ◆ Requires full Orbiter certification

## 4. Tougher Lower Surface Tile

### TPS Enhancements

Change Item	Rationale for Change
<b>2. Tougher Tile</b>	
<b>BRI 8</b>	
<b>BRI 8 Development</b>	Use of BRI 8 is intended to replace HRSI LI900 tiles. Use of more impact resistant lower surface acreage tile is expected to be more durable against low velocity (ascent type) and high velocity (MMOD type) impacts
<b>BRI 8 Certification</b>	Use of BRI 8 is intended to replace HRSI LI900 tiles. Use of more impact resistant lower surface acreage tile is expected to be more durable against low velocity (ascent type) and high velocity (MMOD type) impacts
<b>Lower Acreage Implementation</b>	Use of BRI 8 is intended to replace HRSI LI900 tiles. Use of more impact resistant lower surface acreage tile is expected to be more durable against low velocity (ascent type) and high velocity (MMOD type) impacts
<b>BRI 20</b>	
<b>BRI 20 development</b>	Use of BRI 20 is intended to replace HRSI LI2200 and near term HRSI FRCI 12 type tiles. Use of more impact resistant tile around door peripheries (ET, NLGD, MLGD), window frames, WLESS carrier panels, and Elevon leading edge and Wing Trailing Edge Carrier panel tiles is expected to be more durable against low velocity (ascent type) and high velocity (MMOD type) impacts
<b>BRI 20 Certification</b>	Use of BRI 20 is intended to replace HRSI LI2200 and near term HRSI FRCI 12 type tiles. Use of more impact resistant tile around door peripheries (ET, NLGD, MLGD), window frames, WLESS carrier panels, and Elevon leading edge and Wing Trailing Edge Carrier panel tiles is expected to be more durable against low velocity (ascent type) and high velocity (MMOD type) impacts
<b>BRI 20 Implementation: 1. ET Door periphery; 2. MLGD periphery; 3. NLGD periphery, 4. Elevon Leading Edge carrier panels; 5. Wing Trailing Edge carrier panels; 6. Window Frames</b>	Use of more impact resistant tile around ET Door periphery, MLG Door periphery, NLG Door periphery, Elevon Leading Edge carrier panels, Wing Trailing Edge carrier panels, and Window Frames is expected to be more durable against low velocity (ascent type) and high velocity (MMOD type) impacts

## 4. Tougher Lower Surface Tile (BRI 8/12/20) Forward Plan

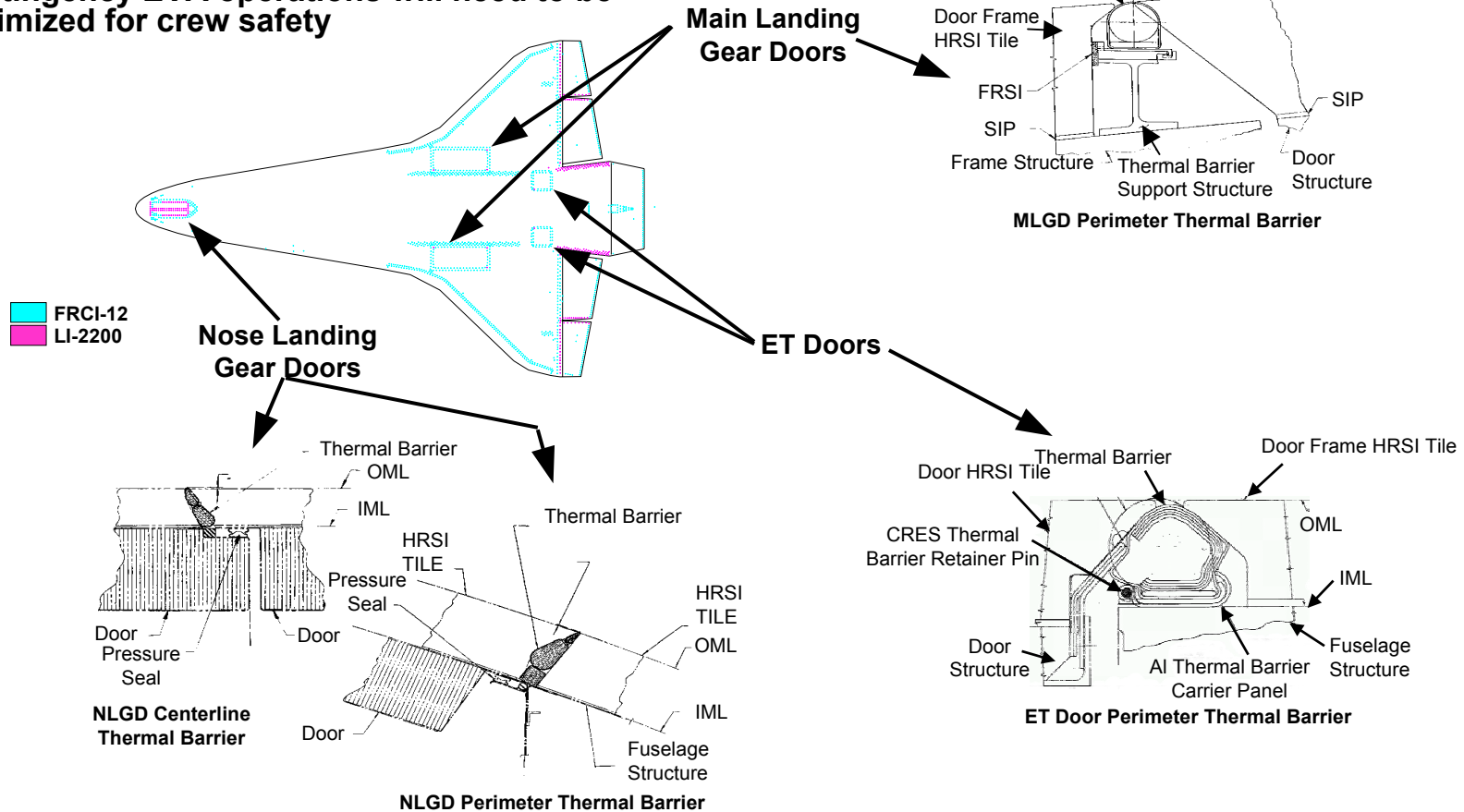
*TPS Enhancements*

Change Item	Rationale for Change
<b>Ballistic SIP</b>	
Ballistics SIP Development	Use of ballistic SIP with BRI 8 tiles has been shown to provide impact resistance against MMOD impacts.
Ballistic SIP Certification	Use of ballistic SIP with BRI 8 tiles has been shown to provide impact resistance against MMOD impacts.
<b>BRI 12</b>	
BRI 12 Development	Use of BRI 12 is intended to replace HRSI FRCI 12 type tiles. Use of 12 pound tiles instead of 20 pound tiles can save vehicle weight addition. Use of more impact resistant tile is expected to be more durable against low velocity (ascent type) and high velocity (MMOD type) impacts
BRI 12 Certification	Use of BRI 12 is intended to replace HRSI FRCI 12 type tiles. Use of 12 pound tiles instead of 20 pound tiles can save vehicle weight addition. Use of more impact resistant tile is expected to be more durable against low velocity (ascent type) and high velocity (MMOD type) impacts

## 2. Landing Gear & ET Door TPS - Issues

### TPS Enhancements

- Impact damage to door, frames, TPS & thermal seals can cause LOV
- Contingency EVA inspection & repair will be difficult & complex
- Contingency EVA operations will need to be minimized for crew safety



## 2. Door (MLGD, NLGD, ETD) Redesign

*TPS Enhancements*

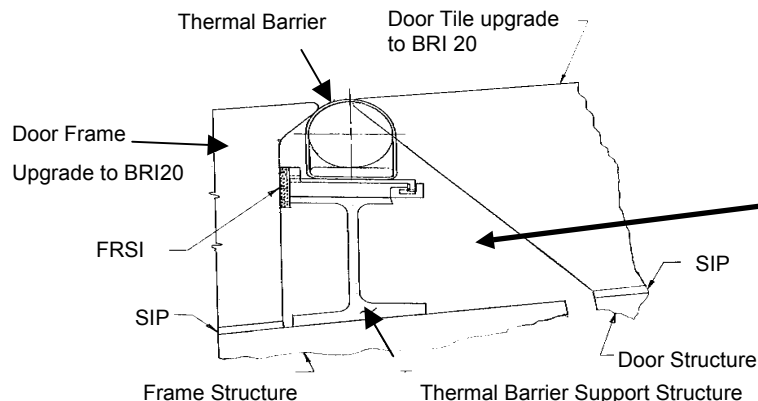
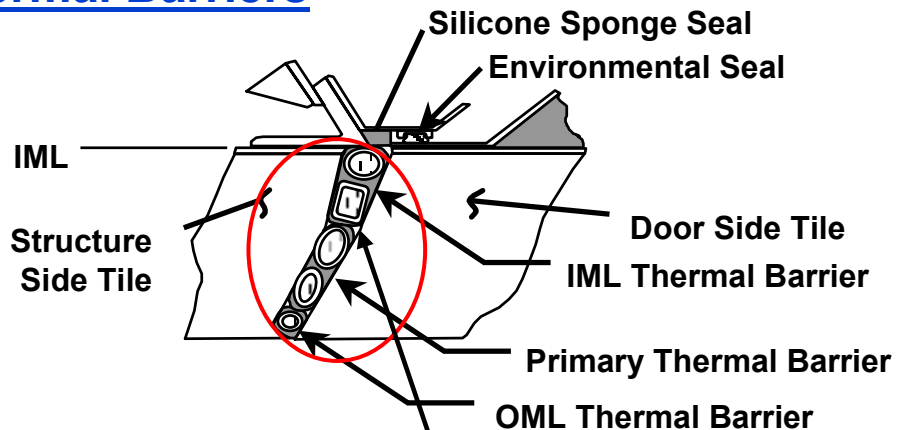
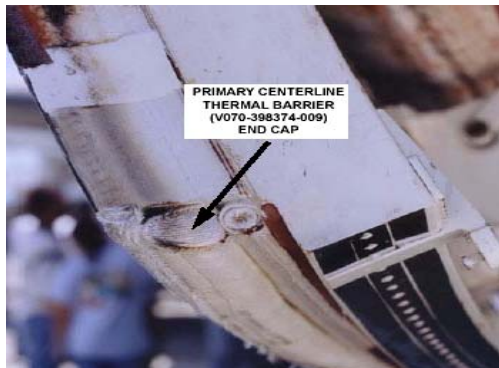
- ◆ **Door (MLGD, NLGD, and ET Door) seal requirements need to be verified - UA Closure Team Recommendation**
  - ◆ Verified intent to be a pressure seal
  - ◆ Study required to determine if seals can be verified with existing design
    - ◆ Potential design modification or other method required to allow seal verification every flight
- ◆ **MLGD Redesign**
  - ◆ Fill MLGD corner void
  - ◆ Thermal Barrier System Redesign
    - ◆ Redesign MLGD seal design to be similar to Modified NLGD Thermal Barrier Design Approach
      - ◆ Bond in redundant thermal barriers
    - ◆ Add preformed insulation to existing and new thermal barriers
    - ◆ Upgrade thermal barrier material to higher temperature Nextel fabrics
- ◆ **NLGD Redesign**
  - ◆ Existing Thermal Barrier Simple Upgrades
    - ◆ Change thermal barrier batting material to preformed insulation
    - ◆ Upgrade thermal barrier material to higher temperature Nextel fabrics
- ◆ **ET Door Redesign**
  - ◆ Existing Thermal Barrier Simple Upgrades
    - ◆ Add preformed insulation to existing thermal barriers
    - ◆ Upgrade thermal barrier material to higher temperature Nextel fabrics

## 2. Door (MLGD, NLGD, ETD) Redesign - MLGD Redesign to Add Redundant Bonded in Thermal Barriers

*TPS Enhancements*

- ◆ **NLGD Thermal Barriers are a Redundant System unlike MLGD**
  - ◆ Multiple Thermal Barriers Provide Backup Capacity
- ◆ **NLGD Thermal Barriers are bonded to the STR side tile sidewalls, chin panel RCC, and to the Inconel ET Bearing plate bracket located in the center AFT of the door**
  - ◆ The OML Thermal barriers are bonded with ceramic based adhesive due to high bondline temperature. IML and Primary Thermal barriers are mainly installed with RTV

### NLGD Thermal Barriers



MLGD

**Implement This NLGD  
Feature (bonded on thermal barriers)  
on MLGD**

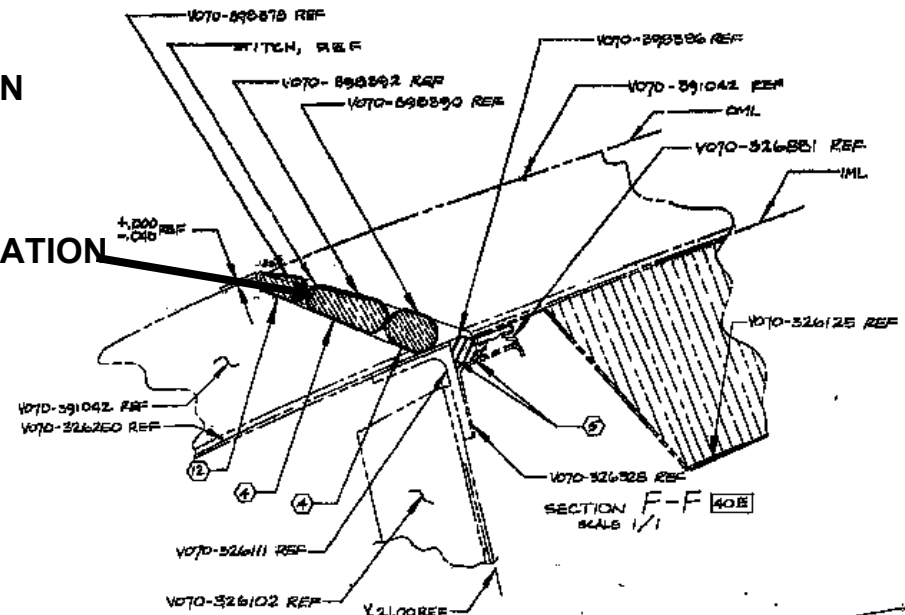
## TPS Enhancements

- ◆ Applies to MLGD, NLGD, and ETD

- 
- ETD**
- MLGD**
- ADD IN**
- CHANG**
- V070-199048 REF
- OML
- PLANE P
- IML
- V070-199006 REF

## ADD INSULATION

## CHANGE INSULATION



# NLGD

## 2. Door (MLGD, NLGD, ETD) Redesign Forward Plan

### *TPS Enhancements*

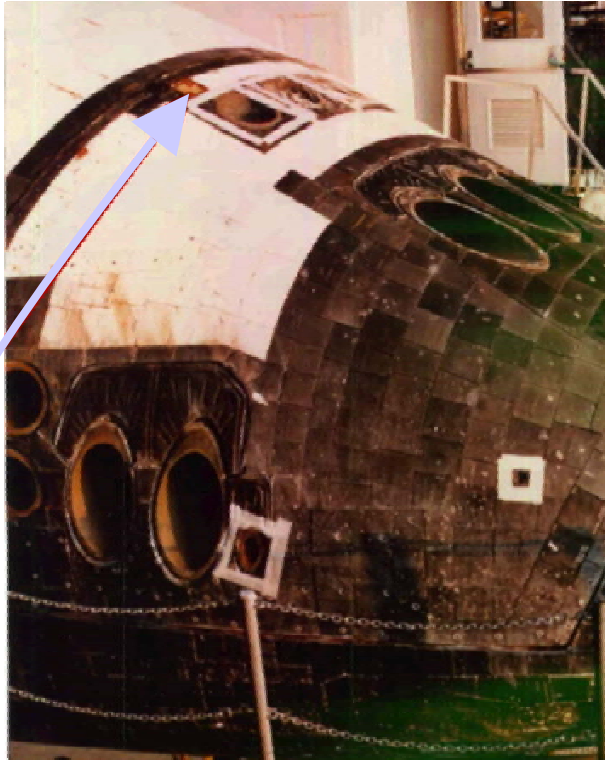
Change Item	Rationale for Change
<b>3. Door (MLGD, NLGD, ETD) Redesign</b>	
<b>MLGD Redesign</b>	
Fill Corner Void	Elimination of corner void, eliminates existing flow path (complete August 2003)
Redundant Thermal Barrier System/Periphery Tile Upgrade	<p><b>1.</b> Multiple thermal barriers provides backup for temperature resistance and prevention of plasma flow beyond barrier system. <b>2.</b> Use of more impact resistant tile around MLG door peripheries is expected to be more durable against low velocity (ascent type) and high velocity (MMOD type) impacts. <b>3.</b> Addition of more temperature resistant thermal barrier materials provides better protection against high temperatures and is expected to allow for more time for Shuttle to survive reentry conditions in the event of a breach in the door area. <b>Goal</b> is to make design similar to NLGD thermal barrier design (bonded in thermal barriers) and upgrade thermal barrier materials.</p>
<b>NLGD Redesign</b>	
Thermal Barrier System Upgrade for Temperature Resistance	Addition of more temperature resistant thermal barrier materials provides better protection against temperatures and is expected to allow for more time for Shuttle to survive reentry conditions in the event of a breach in the door area
<b>ETD Redesign</b>	
Redundant Thermal Barrier System (ORTFWG study request)	Multiple thermal barriers provides backup for temperature resistance and prevention of plasma flow beyond barrier system.
Thermal Barrier System Upgrade for Temperature Resistance	Addition of more temperature resistant thermal barrier materials provides better protection against temperatures and is expected to allow for more time for Shuttle to survive reentry conditions in the event of a breach in the door area.

# 3. Carrier Panel Redesign To Eliminate Bonded Studs

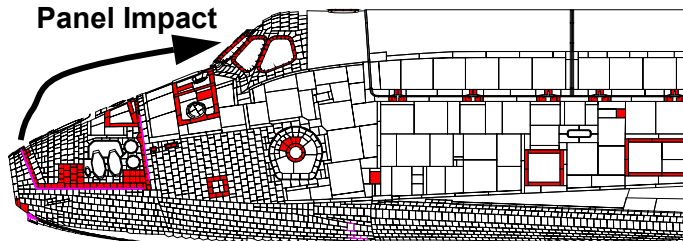
## FRCS TPS Carrier Panels - Issues

### *TPS Enhancements*

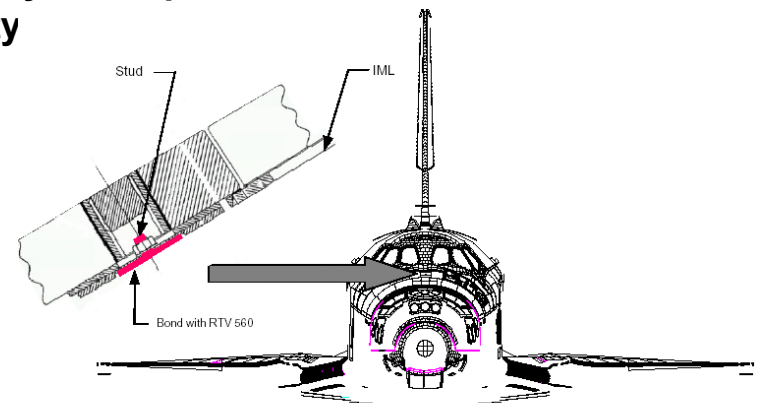
- Impact damage to TPS carrier panels or attachments can cause LOV
- Lost carrier panels can impact critical vehicle areas
  - E.g. FRCS panels into windows during ascent
- In contingency situations:
  - Bonded studs may not respond to impact loads without failure
  - Fasteners that have lost torque may release
  - Nut plates & inserts that have limited self-locking life may lose torque
  - Panels with only 2 fasteners are not fail-safe
- No back-up or redundancy if TPS or panel damaged
- Contingency EVA inspection & repair will be difficult & complex
- Contingency EVA operations will need to be minimized for crew safety



Potential Lost Carrier Panel Impact



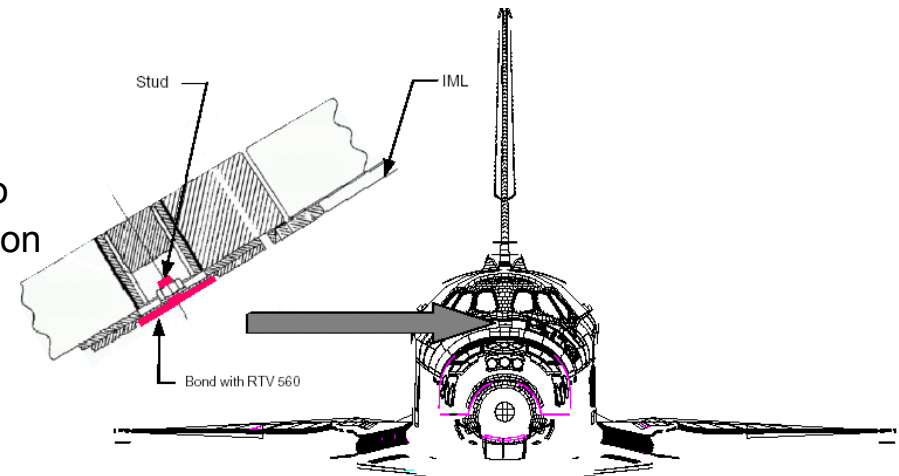
Carrier Panel Locations



### 3. Carrier Panel Redesign TIM Actions

*TPS Enhancements*

- ♦ **Eliminate use of bonded studs for future design – UA Closure Team recommendation**
- ♦ **Perform analysis to ensure positive margins exist if studs are completely debonded – UA Closure Team recommendation**
  - ♦ Boeing Structures team confirmed bonded studs added since installation was negative margin without
- ♦ **Define all bonded stud locations installed by MR; PRCA search currently in-work**
- ♦ **Redesign if cannot “return to print” to threaded fasteners for location studs bonded by MR - UA Closure Team recommendation**
- ♦ **Determine if increasing fastener size will maintain positive margin if current bonded studs missing**
- ♦ **Where not possible, study redesign of FRCS carrier panel attachment to add threaded fastener in place of design bonded studs**
  - ♦ Redesign Tile array pattern as required
  - ♦ Investigate use of self locking bolts
  - ♦ Investigate feasibility of increasing carrier panel thickness and/or fastener diameter to gain margin in lieu of bonded stud elimination



### 3. Carrier Panel Redesign Forward Plan

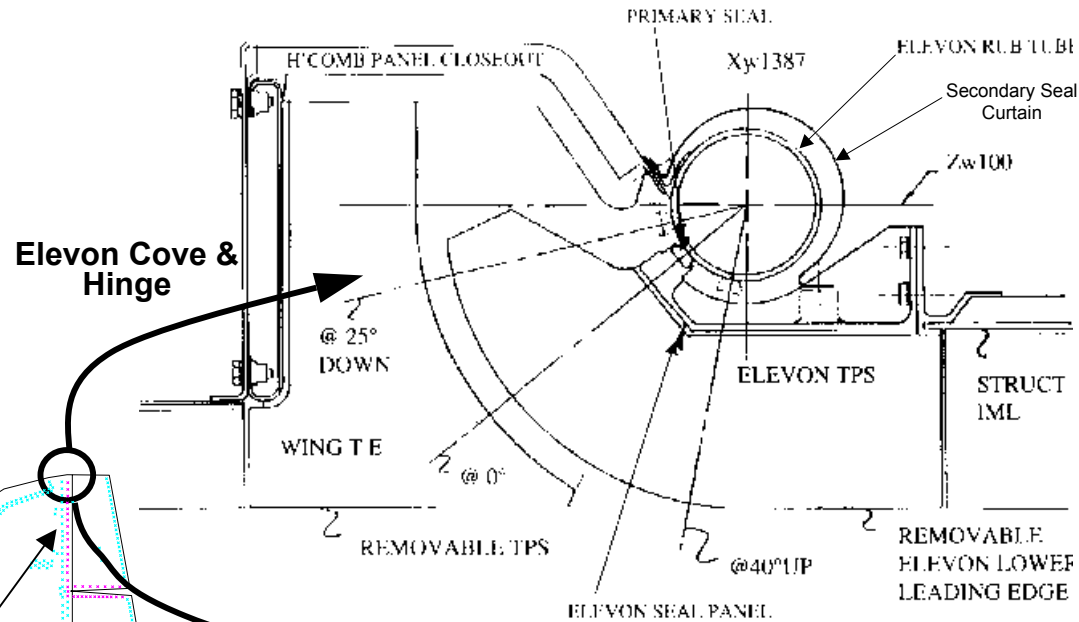
*TPS Enhancements*

Change Item	Rationale for Change
<b>4. Carrier Panel Upgrades to Eliminate Bonded Studs</b>	
<b>Redesign FRCS Carrier Panel</b>	FRCS carrier panel installation is negative margin if a bonded stud is lost. Redesign to reduce risking loss of carrier panel attachment positive margin and potential loss of carrier panel due to impact, or other means.
<b>Redesign TBD carrier panels with MR bonded Studs</b>	FRCS carrier panel installation is negative margin if a bonded stud is lost. Redesign to reduce risking loss of carrier panel attachment positive margin and potential loss of carrier panel due to impact, or other means.

# 5. Elevon Cove Leading Edge Carrier Panel- Issues

## TPS Enhancements

- LE carrier panels are fastened to seal panel using self locking thin wall inserts. Mods to carrier panels have added tension preload to fasteners
- Failure of insert or fastener due to impact of other reasons would expose primary seal panel to direct hot gas during entry
- Contingency EVA inspection & repair will be difficult & complex
- Contingency EVA operations will need to be minimized for crew safety



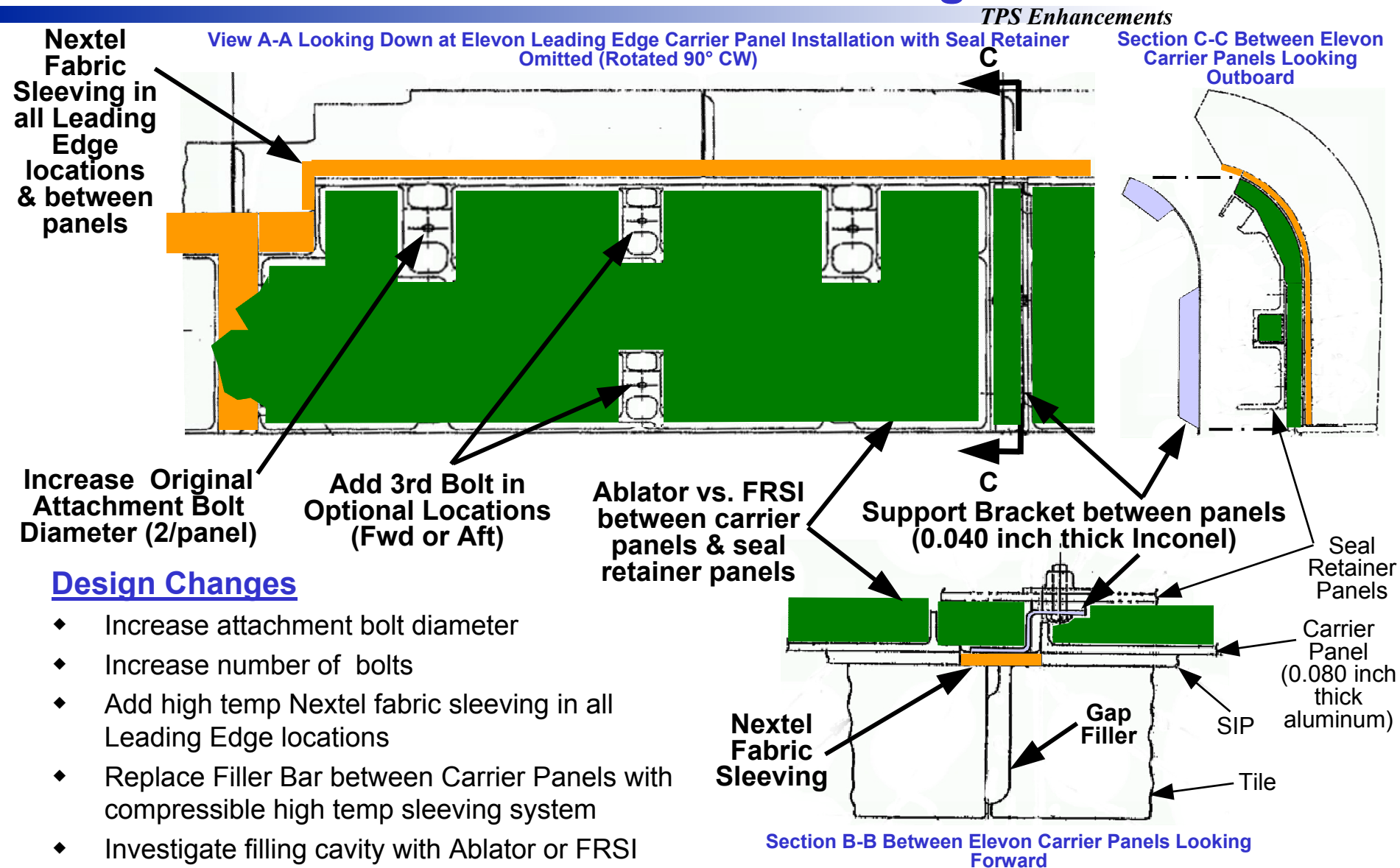
Example damage on OV-103 STS-51D



Elevon Coves

FRCI-12  
LI-2200

# 5. Elevon Cove Leading Edge Carrier Panel Redesign - Elevon LE Carrier Panel Instl – Redesign TIM Actions



## 5. Elevon Cove Leading Edge Carrier Panel Forward Plan

*TPS Enhancements*

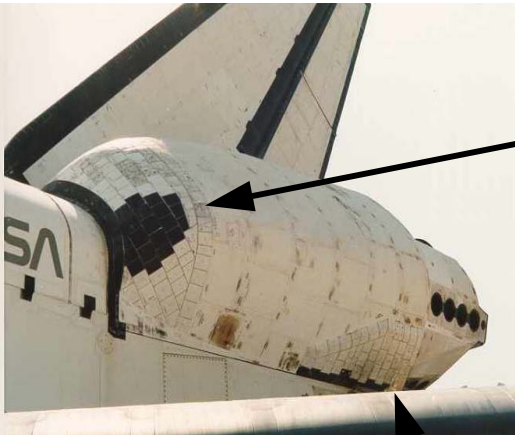
Change Item	Rationale for Change
<b>6. Elevon LE Carrier Panel Redesign</b>	
<b>Elevon LE Carrier Panel Redesign</b>	Redesign access panels to make it more robust against impacts and provide additional protection from plasma flow due to impact damage.

# 6. White TUF1 – Issues - OMS Pod Fwd Dome & Aft Outboard Corner

*TPS Enhancements*

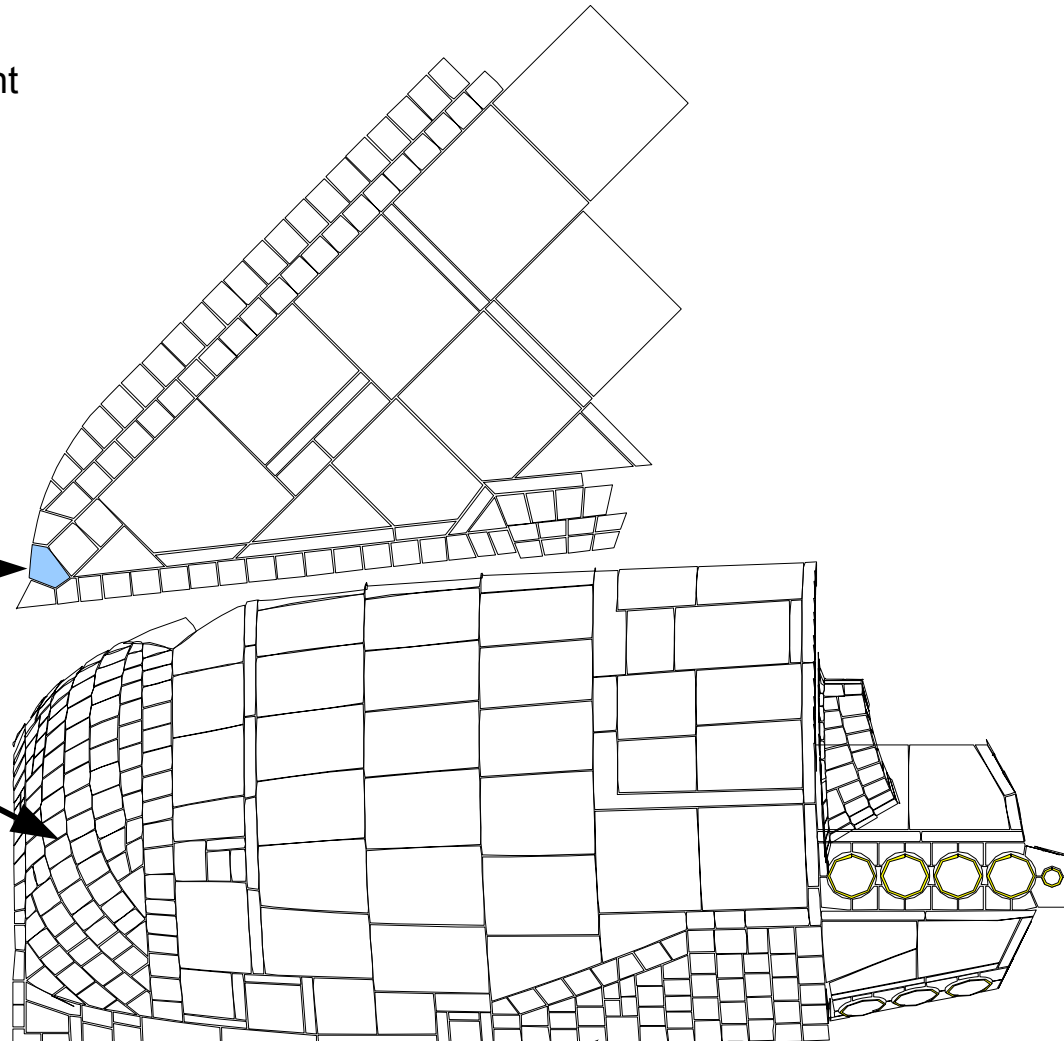
- Impact resistance of OMS Pod increased by prior upgrade from 1 in AFRSI to 2 & 3 in LI-900 & FRCI-12 tile
  - Upgrade to harder White TUF1 tile development on-going
  - Impact protection can still be increased with thinner 5<sup>th</sup>-generation tile systems
- “Cadillac” fitting has low margin at high temperature
  - Does not have heat-sink capability if tile lost

Tile over “Cadillac” Fitting



OMS Pod Dome / Leading Edge  
LI-900 and  
FRCI-12 Tile

OMS Pod Aft Outboard Corner  
LI-900 and FRCI-12 Tile



## 6. Current LRSI Tile Are Delicate, Frequently Damaged, And Difficult To Access For Repair

*TPS Enhancements*

- ◆ **OV-103 & Subs have approximately 700 LRSI tile on upper surface of crew compartment and OMS pods**
  - ◆ OV-103 & subs have 325 LRSI tiles (average)
  - ◆ Each OMS (orbital maneuvering system) pod has 196 LRSI tiles
- ◆ **White RCG (reaction-cured glass) tile coating is used on upper surface to reflect solar energy. Black RCG is used on lower surface to emit radiation during reentry**
- ◆ **White RCG coating is more delicate than black RCG on the lower surface tiles, making it more susceptible to damage**
- ◆ **Forward-facing surfaces of the canopy and the OMS pods are subject to impact damage during ascent**
  - ◆ OV-102 STS-93 had 31 damages to upper surface, 5 > 1"
  - ◆ OV-103 STS-102 had 44 damages to upper surface, 4 > 1"
  - ◆ OV-104 STS-104 had 18 damages to upper surface, 2 > 1"
  - ◆ OV-105 STS-108 had 14 damages to upper surface, 5 > 1"
- ◆ **Upper surface locations are more difficult to access for repair and risk tool drop damage**

## 6. White TUFITIM Forward Plan

*TPS Enhancements*

Change Item	Rationale for Change
<b>7. White TUFITIM</b>	
White TUFITIM development	Upgrade of certain upper surface tile with white TUFITIM tile will make them less susceptible to impact damage
White TUFITIM Certification	Upgrade of certain upper surface tile with white TUFITIM tile will make them less susceptible to impact damage
White TUFITIM implementation Plan	Upgrade of certain upper surface tile with white TUFITIM tile will make them less susceptible to impact damage

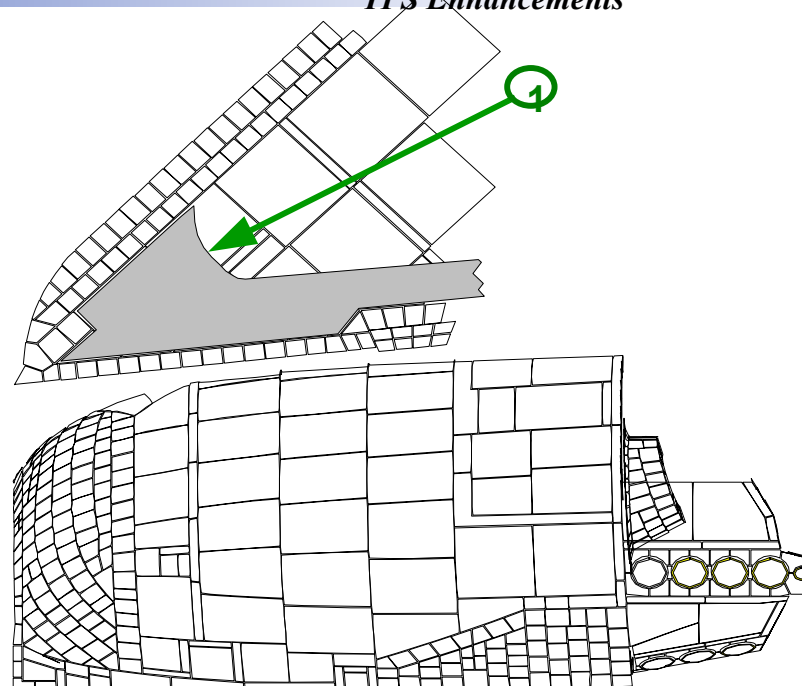
## 6. Vertical Tail AFRSI High-Emittance Coating

*TPS Enhancements*

- ◆ **Vertical tail is limiting factor in contingency trajectories**
  - ◆ Add current gray high emittance coating to side AFRSI blankets

### **BENEFITS:**

- ◆ **Expanded contingency low-alpha reentry trajectory limits**
- ◆ **Guidance control assessment for contingency trajectories required in study**
- ◆ **Impacts of contingency limits to other systems required in study**



Change Item	Rationale for Change
8. Vertical Tail AFRSI High Emittance Coating	
	Potential exist to expand contingency low-alpha reentry trajectory limits